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Yen et al.

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(54) **SIGNAL PROCESSING SYSTEM WITH BIST FUNCTION, TESTING METHOD THEREOF AND TESTING SIGNAL GENERATOR**

(71) Applicant: **MStar Semiconductor, Inc.**, Hsinchu Hsien (TW)

(72) Inventors: **Shih-Chieh Yen**, ChuPei (TW); **Chih-Ming Hung**, ChuPei (TW)

(73) Assignee: **MStar Semiconductor, Inc.**, Hsinchu Hsien (TW)

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(22) Filed: **May 9, 2014**

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(30) **Foreign Application Priority Data**

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G01R 31/317 (2006.01)
G01R 31/28 (2006.01)

(52) **U.S. Cl.**
CPC ***G01R 31/31715*** (2013.01); ***G01R 31/2822*** (2013.01); ***H04B 17/0085*** (2013.01)

(58) **Field of Classification Search**
CPC H04B 17/00; H04B 17/0085; G01R 31/2822; G01R 31/31715
See application file for complete search history.

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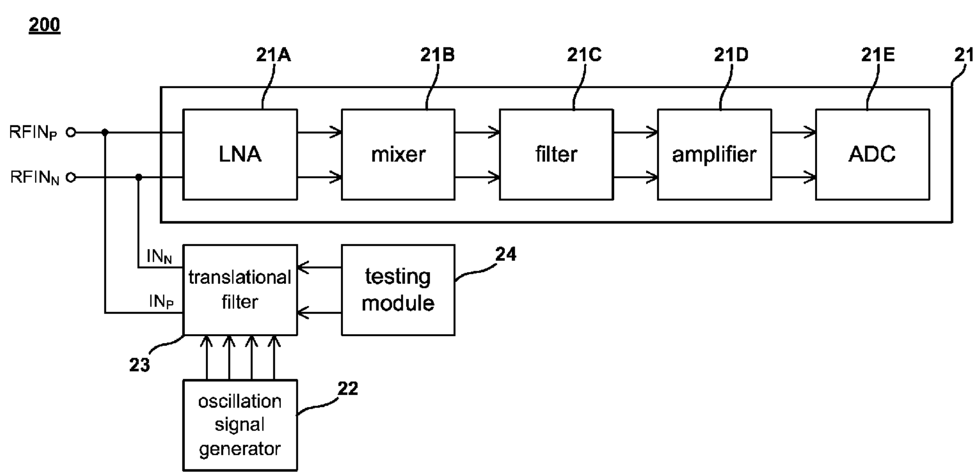
Primary Examiner — Steve Nguyen
(74) *Attorney, Agent, or Firm* — Edell, Shapiro & Finnan, LLC

(57) **ABSTRACT**

A signal processing system includes a module under test, an oscillation signal generator, a translational filter, and a testing module. The module under test has a signal input end. The oscillation signal generator generates an oscillation signal. The translational filter includes a mixer controlled by the oscillation signals. The mixer has a high-frequency side and a low-frequency side. The high-frequency side is coupled to the signal input end of the module under test. The testing module is coupled to the low-frequency side of the mixer. When the signal processing system is in a testing mode, the testing module provides a testing signal to the low-frequency side, so as to generate a high-frequency testing signal at the high-frequency side of the mixer.

19 Claims, 8 Drawing Sheets



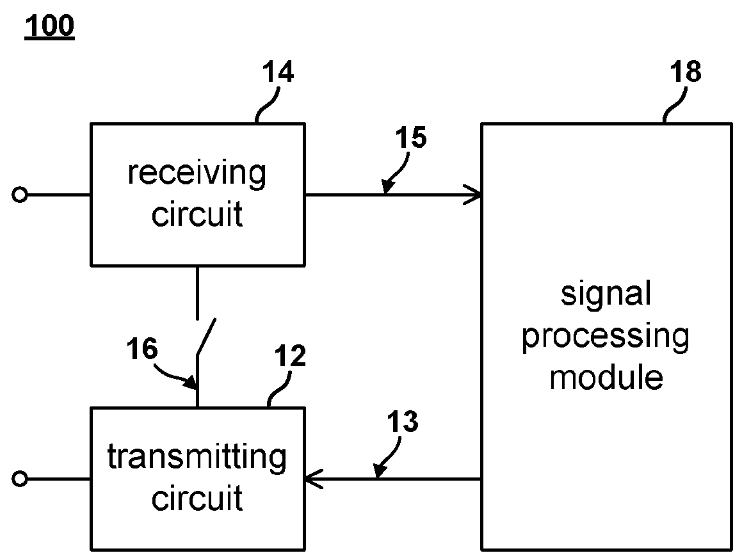


FIG. 1 (prior art)

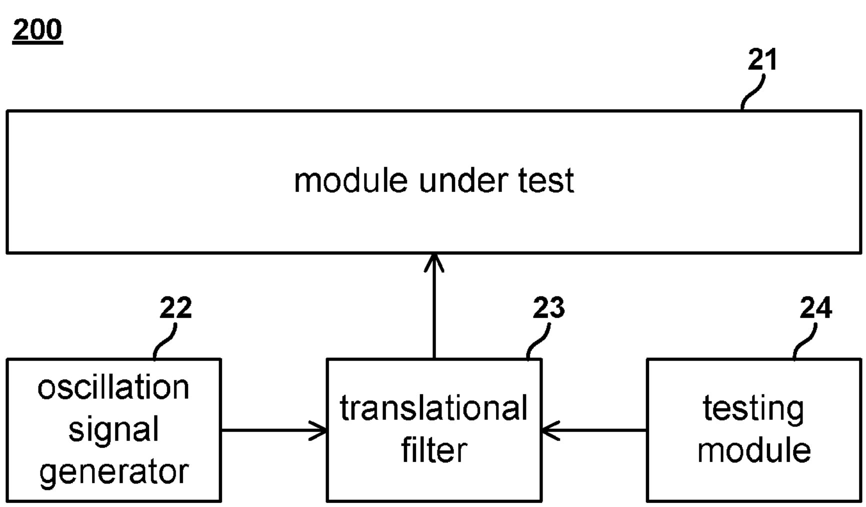
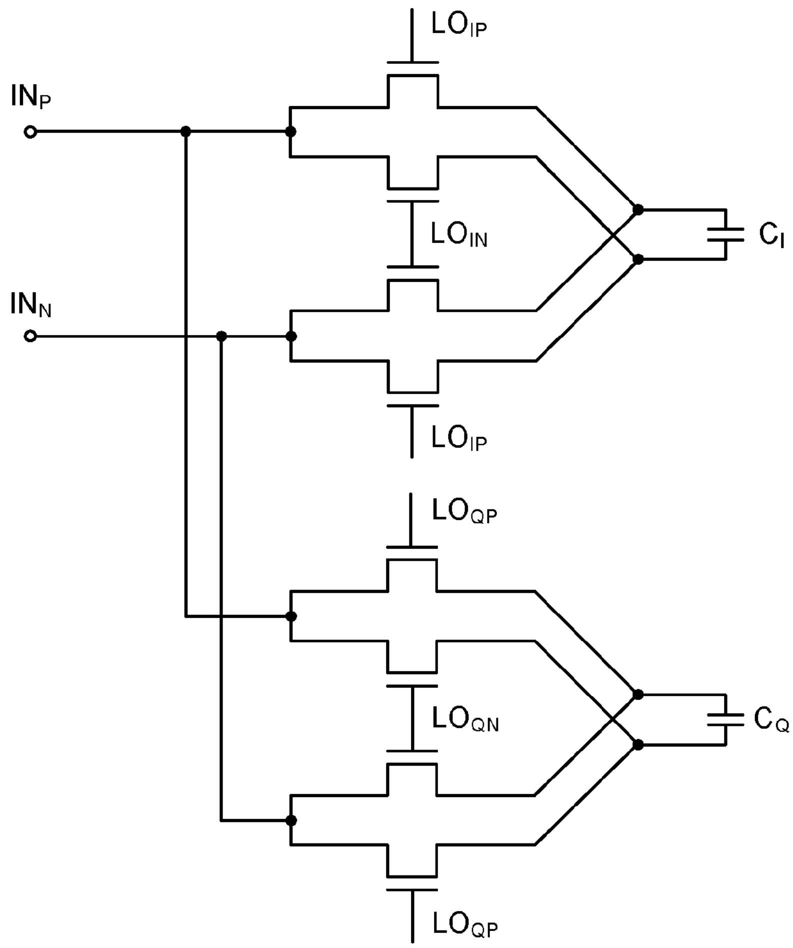
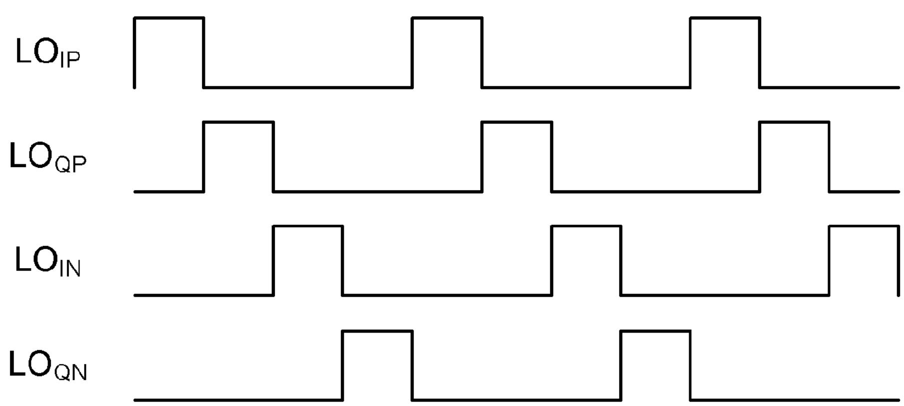


FIG. 2



LO_{IP}
IN_P
LO_{IN}
C_I
IN_N
LO_{IP}
LO_{QP}
LO_{QN}
C_Q
LO_{QP}

FIG. 3A



LO_{IP}
LO_{QP}
LO_{IN}
LO_{QN}

FIG. 3B

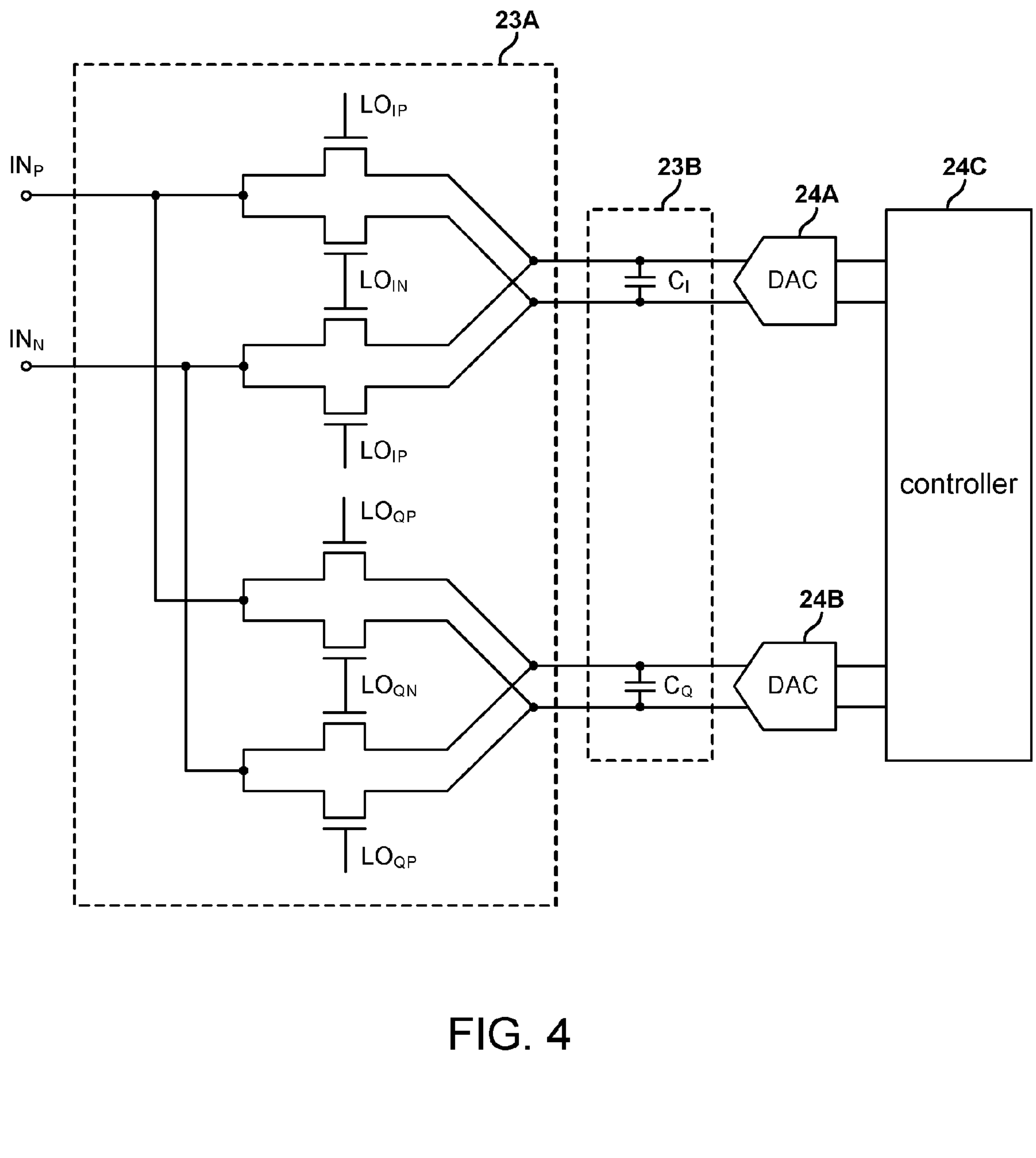

23A
LO_{IP}
IN_P
23B
24A
24C
LO_{IN}
C_I
DAC
IN_N
LO_{IP}
controller
LO_{QP}
24B
LO_{QN}
C_Q
DAC
LO_{QP}

FIG. 4

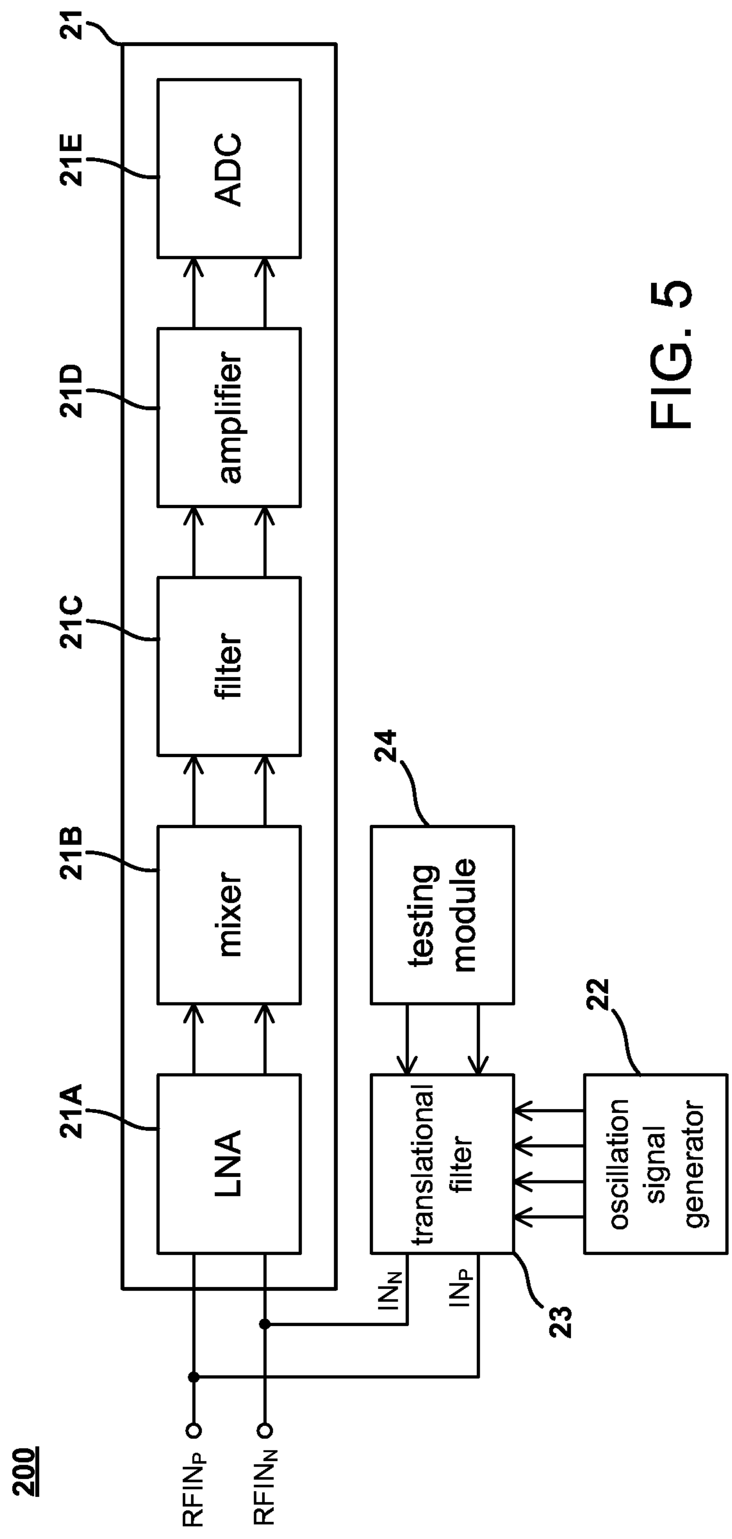

200
RFIN_P
RFIN_N
21
21A
21B
21C
21D
21E
LNA
mixer
filter
amplifier
ADC
24
testing module
IN_N
IN_P
translational filter
23
22
oscillation signal generator

FIG. 5

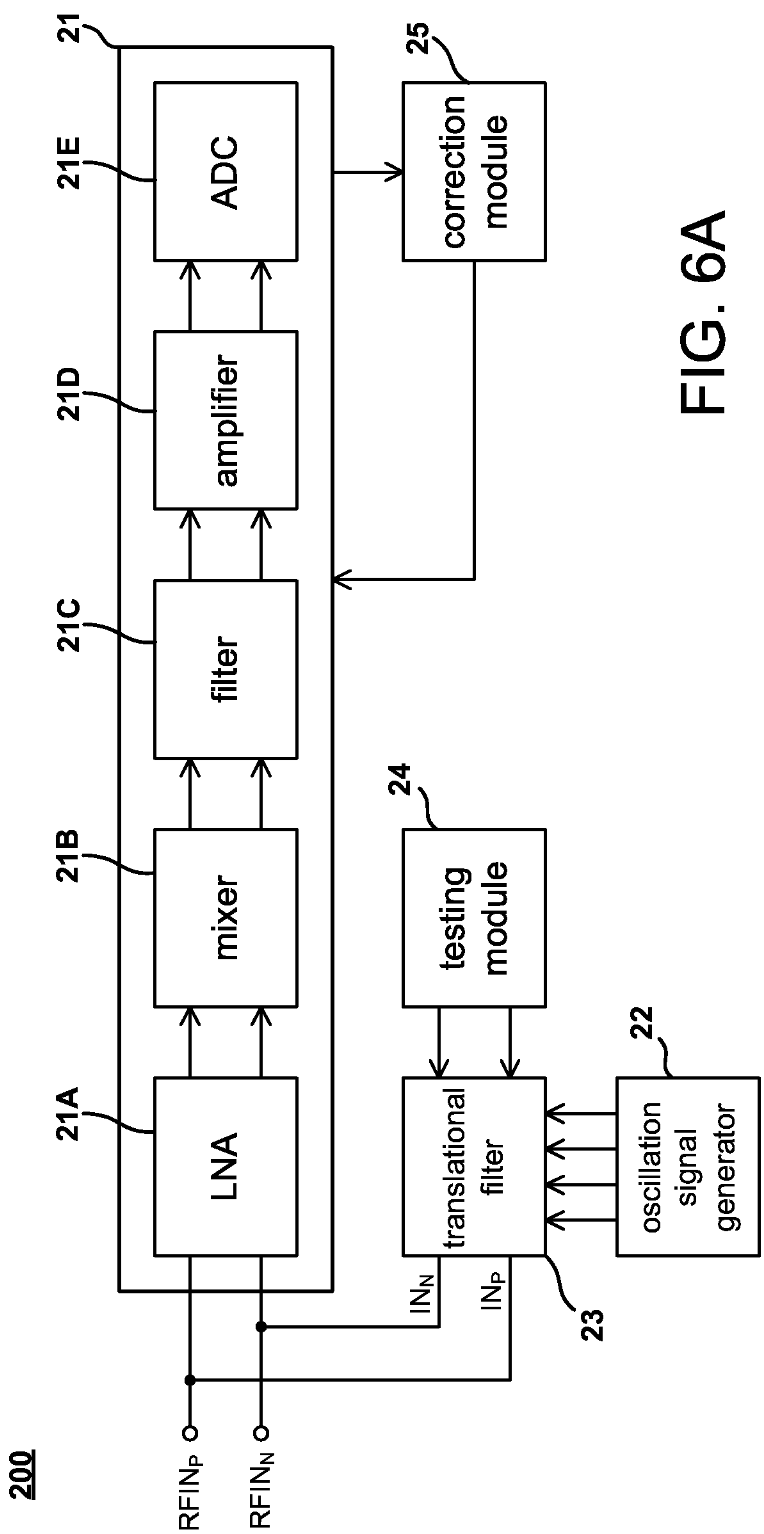

200
RFIN_P
RFIN_N
21
21A
LNA
21B
mixer
21C
filter
21D
amplifier
21E
ADC
25
correction module
24
testing module
IN_N
IN_P
translational filter
23
22
oscillation signal generator

FIG. 6A

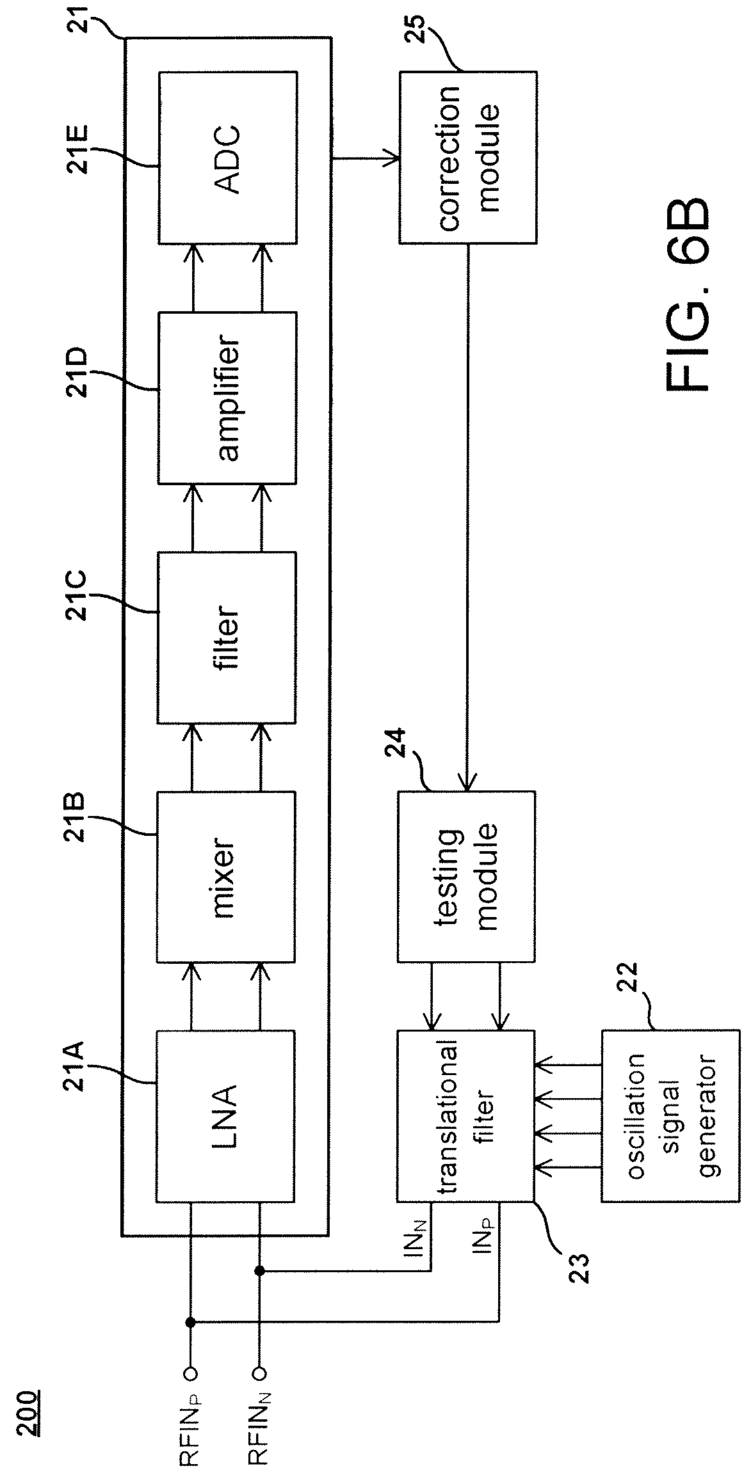

200
RFIN$_P$
RFIN$_N$
21
21A
LNA
21B
mixer
21C
filter
21D
amplifier
21E
ADC
25
correction module
24
testing module
IN$_N$
IN$_P$
translational filter
23
22
oscillation signal generator

FIG. 6B

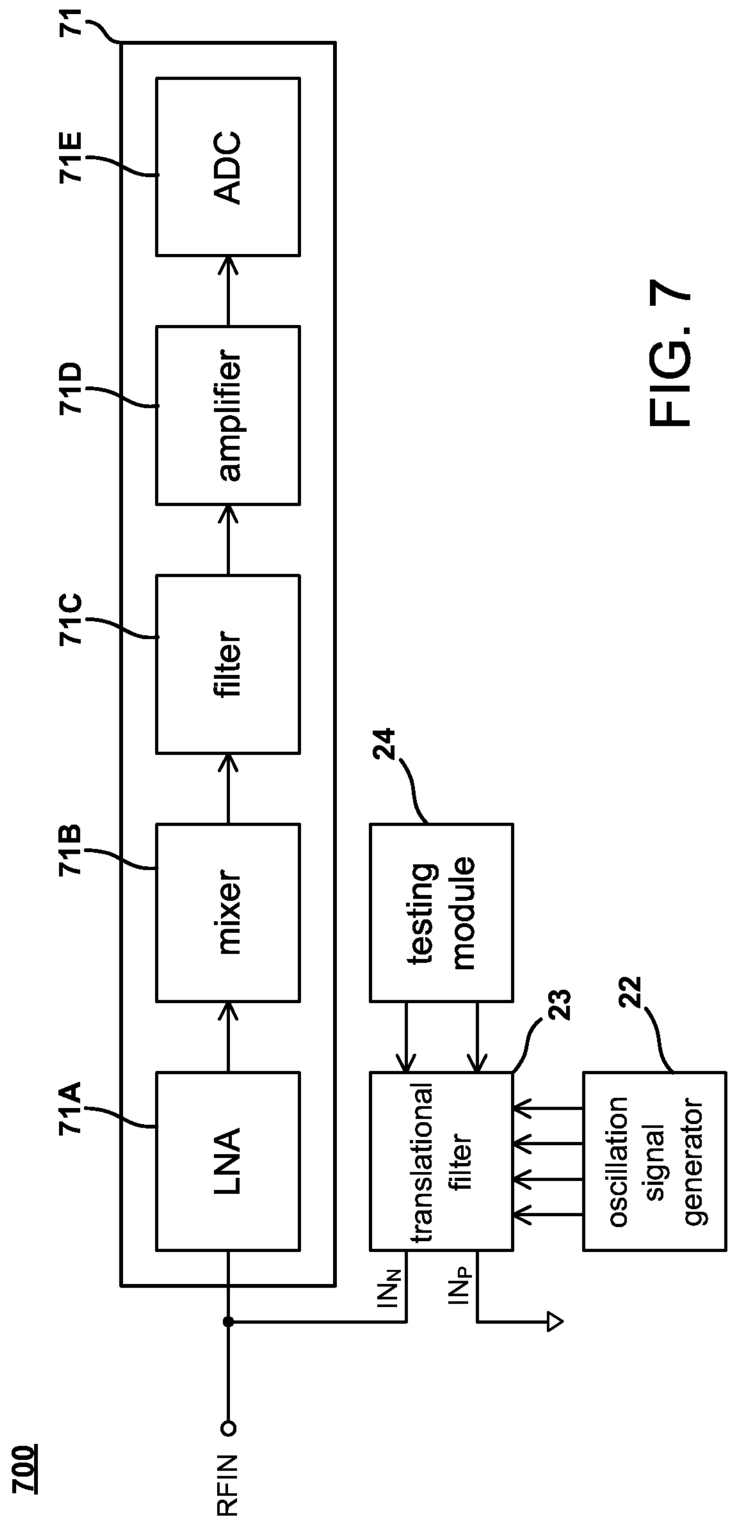

700
RFIN
71
71A
LNA
71B
mixer
71C
filter
71D
amplifier
71E
ADC
24
testing module
23
translational filter
22
oscillation signal generator
IN_N
IN_P

FIG. 7

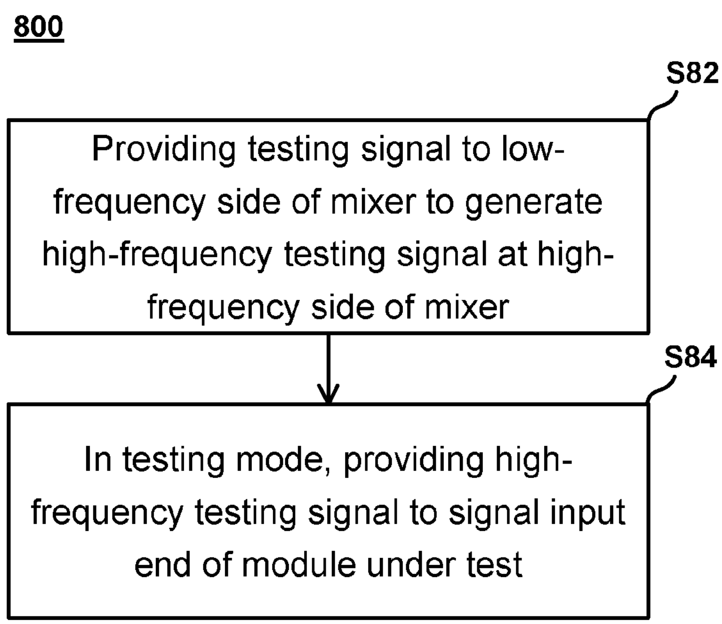

800
S82
Providing testing signal to low-frequency side of mixer to generate high-frequency testing signal at high-frequency side of mixer
S84
In testing mode, providing high-frequency testing signal to signal input end of module under test

FIG. 8

SIGNAL PROCESSING SYSTEM WITH BIST FUNCTION, TESTING METHOD THEREOF AND TESTING SIGNAL GENERATOR

This application claims the benefit of Taiwan application Serial No. 102120298, filed Jun. 7, 2013, the subject matter of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates in general to a testing technology for a computer system, and more particularly, to a signal processing system with a built-in self-test (BIST) function.

2. Description of the Related Art

Ensuring normal functionality of products when the products are shipped out of the factory is always a focus of manufacturers. By pre-filtering out and repairing problematic products, post-sales returns and exchanges can be effectively prevented to increase customer satisfaction.

For an electronic system, a most common test item is inputting a simulation signal at an input end of a circuit and monitoring whether a processed result outputted at a rear-end is correspondingly a correct output signal. Taking a communication system **100** simultaneously including a transmitting circuit **12** and a receiving circuit **14** in FIG. **1** for example, a current testing method is establishing a loopback path **16** between the transmitting circuit **12** and the receiving circuit **14**. In a normal mode, the loopback path **16** is set as open circuit, so that the transmitting circuit **12** and the receiving circuit **14** operate independently. In a testing mode, the loopback path **16** is set as close circuit, such that the signal processing module **18** controls the transmitting circuit **12** to provide a testing signal **13** via the loopback path **16** to the receiving circuit **14**. According to a response signal **15** outputted by the receiving circuit **14**, the signal processing module **18** determines whether the transmitting circuit **12** and the receiving circuit **14** are functional.

An advantage of the architecture shown in FIG. **1** is that no additional signal source for providing the testing signal is involved, and thus costs of testing apparatuses can be reduced. However, the testing architecture in FIG. **1** is unsuitable for applications of several signal processing systems below: 1) a signal processing system in which a dynamic output range of a transmitting circuit is different from that of a receiving circuit; 2) a signal processing system that does not allow simultaneous operations of a transmitting circuit and a receiving circuit; 3) a signal processing system in which a coupling path between a transmitting circuit and a receiving circuit is strictly prohibited; and 4) a signal processing system that includes only a receiving circuit but not a transmitting circuit.

For the above situations, a simulation input signal usually needs to be externally provided from a testing machine to test whether a receiving circuit is normal. However, signal frequencies to be processed by front-end circuits in many signal processing systems (e.g., a wireless communication apparatus) are quite high. As costs of testing apparatuses that can generate high-frequency testing signals are very high, overall testing costs are inevitably increased by considerable amounts.

SUMMARY OF THE INVENTION

The invention is directed to a signal processing system with a built-in self-test (BIST) function and a testing method thereof. With a translational filter that generates a testing signal in a chip, overall testing costs can be significantly lowered. Further, in additional to a transmitting circuit included in a same signal processing system, the testing method of the present invention is also applicable to a signal processing system that does not include a transmitting circuit.

According to an embodiment of the present invention, a signal processing system is provided. The signal processing system includes a module under test, an oscillation signal generator, a translational filter and a testing module. The module under test has a signal input end. The oscillation signal generator generates an oscillation signal. The translational filter includes a mixer controlled by the oscillation signal. The mixer has a high-frequency side and a low-frequency side. The high-frequency side is coupled to the signal input end of the module under test. The testing module provides a testing signal to the low-frequency side, so as to generate a high-frequency testing signal at the high-frequency side of the mixer.

According to another embodiment of the present invention, a testing method that generates a high-frequency testing signal by a translational filter is provided. The translational filter includes a mixer, which has a high-frequency side and a low-frequency side. In a testing mode, a testing signal is provided to the low-frequency side, so as to generate a high-frequency testing signal at the high-frequency side of the mixer. Next, the high-frequency testing signal is provided to a signal input end of a module under test. In a normal operation mode relative to the testing mode, the translational filter provides the module under test with a filtering function.

According to yet another embodiment of the present invention, a testing signal generator is provided. The testing signal generator, providing a high-frequency testing signal to a signal input end of a module under test, includes an oscillation signal generator, a translational filter and a testing module. The oscillation signal generator generates an oscillation signal. The translational filter includes a mixer controlled by the oscillation signal. The mixer has a high-frequency side and a low-frequency side. The high-frequency side is coupled to the signal input end of the module under test. The testing module provides a testing signal to the low-frequency side, so as to generate the high-frequency testing signal at the high-frequency side of the mixer.

The above and other aspects of the invention will become better understood with regard to the following detailed description of the preferred but non-limiting embodiments. The following description is made with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a functional block diagram of a communication system that includes a transmitting circuit, a receiving circuit, and a loopback path for testing purposes;

FIG. **2** is a functional block diagram of a signal processing system according to an embodiment of the present invention;

FIG. **3**(A) is a detailed example of a translational filter;

FIG. **3**(B) is a exemplary timing diagram of local oscillation signals utilized by a translational filter;

FIG. **4** are detailed examples of a translational filter and a testing module according to an embodiment of the present invention;

FIG. **5** is a detailed example of a signal processing system according to an embodiment of the present invention;

FIG. 6(A) and FIG. 6(B) are two examples of a signal processing system further including a correction module according to alternative embodiments of the present invention;

FIG. 7 is a schematic diagram of applying the concept of the present invention to a device under test that has one single input end; and

FIG. 8 is a flowchart of a correcting method according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 2 shows a functional block diagram of a signal processing system with a built-in self-test (GIST) function according to an embodiment of the present invention. As shown in FIG. 2, a signal processing system **200** includes a module under test **21**, an oscillation signal generator **22**, a translational filter **23**, and a testing module **24**. In practice, the signal processing system **200** may be integrated in various electronic devices, e.g., desktop computers, laptop computers, smart phones and LAN access points, or may be an independent device. Further, in practice, the module under test **21** may be a signal receiving circuit.

FIG. 3(A) shows a detailed example of a translational filter according to an embodiment of the present invention. In this example, the translational filter includes a mixer formed by eight metal-oxide semiconductor field-effect transistors (MOSFETs), and capacitor elements C_I and C_Q. The mixer is controlled by local oscillation signals LO_{IP}, LO_{IN}, LO_{QP} and LO_{QN}. The four local oscillation signals have the same frequency but different phases. FIG. 3(B) shows an exemplary timing diagram of the local oscillation signals. Known to a one skilled person in the art, the capacitor elements C_I and C_Q located at a low-frequency side of the mixer are low-pass filters. Through effects of the mixer, the low-pass frequency resonance is translated to a bandpass frequency resonance. More specifically, for signals carried at a high-frequency side (differential input ends IN_P and IN_N) of the mixer, the translational filter is in overall equivalent to a bandpass filter, whose central frequency is the frequencies of the local oscillation signals LO_{IP}, LO_{IN}, LO_{QP} and LO_{QN}. Thus, by adjusting the frequencies of the local oscillation signals, the central frequency of the bandpass filter can be changed. Featuring a high quality factor and a central frequency that can be accurately controlled, translational filters are extensively applied in wireless communication systems and are utilized to filter and obtaining signals within a predetermined target frequency band for front-end receiving circuits.

FIG. 4 shows a detailed example of the translational filter **23** and the testing module **24** according to an embodiment of the present invention. In the example, the translational filter **23** includes a mixer **23**A, and a baseband filtering circuit **23**B coupled to the low-frequency side of the mixer **23**A; the testing module **24** includes digital-to-analog converters (DACs) **24**A and **24**B and a controller **24**C. The oscillation signals LO_{IP}, LO_{IN}, LO_{QP} and LO_{QN} for controlling the mixer **23**A may be provided by the oscillation signal generator **22**. When the signal processing system **200** is in a testing mode, the controller **24**C provides a set of digital testing signal for the DACs **24**A and **24**B to correspondingly generate a set of analog testing signals. As shown in FIG. 4, the DACs **24**A and **24**B are coupled to the low-frequency side of the mixer **23**A. Based on characteristics of the mixer **23**A, when the DACs **24**A and **24**B provide low-frequency analog signals at the low-frequency side of the mixer **23**A, corresponding high-frequency analog signals are generated at the high-frequency side of the mixer **23**A. The process is in equivalence up-converting the set of low-frequency analog signals according to the frequencies of the oscillation signals LO_{IP}, LO_{IN}, LO_{QP} and LO_{QN}.

FIG. 5 shows a detailed example of the signal processing system **200** according to an embodiment of the present invention. In the example, the module under test **21** is a signal receiving circuit, has a set of differential signal input ends $RFIN_P$ and $RFIN_N$, and includes a low-noise amplifier (LNA) **21**A, a mixer **21**B, a filter **21**C, an amplifier **21**A, and an analog-to-digital converter (ADC) **21**E. As shown in FIG. **5**, nodes IN_P and IN_N at a high-frequency side of the mixer **23**A are respectively coupled to the input ends $RFIN_P$ and $RFIN_N$ of the LNA **21**A. In different modes, the translational filter **23** plays different roles. When the signal processing system **200** is in a normal operation mode, the translational filter **23** provides a bandpass filtering function with the LNA **21**A to assist in filtering signals within a specific target frequency band. In contrast, when the signal processing system **200** is in a testing mode, the translational filter **23** is utilized to up-convert a testing signal generated by the testing module **24** and to thus provide the high-frequency testing signal to the input ends $RFIN_P$ and $RFIN_N$ of the LNA **21**A. That is to say, when the signal processing system **200** is in the testing mode, the oscillation signal generator **22**, the translational filter **23**, and the testing module **24** may be regarded as a testing signal generator that generates a high-frequency testing signal to a signal input end of a module under test.

The frequency and contents of the testing signal generated by the testing module **24** may be determined according to actual requirements, and are not limited to specific patterns. For example, the set of testing signals may also be DC signals. It should be noted that, circuits in the testing module **24** may be adjusted according to desired testing signals, and need not necessarily include the foregoing DACs. Further, in practice, the oscillation signal generator **22** may be designed in a way that the oscillation signals LO_{IP}, LO_{IN}, LO_{QP} and LO_{QN} are adjustable. Thus, the frequency of the testing signal provided to the module under test **21** is also adjustable.

In one embodiment, the oscillation signal generator **22** is an inherent element in the module under test **21** instead of being independently located outside the module under test **21**. For example, when the module under test **21** is a receiving circuit, the oscillation signal generator **22** may be a local oscillation signal generator in the module under test **21**. Such approach helps in reducing overall costs of the signal processing system **200**. Although in the above situation, the oscillation signal generator **22** may not be adjustable, the frequency of the high-frequency testing signal provided by the translational filter **23** may still be adjustable through adjusting the frequency of the testing signal generated by the testing module **24**.

It should be noted that, as the oscillation signal generator **22** and the translational filter **23** are elements originally required in the signal processing system **200**, overall costs for realizing the concept of the present invention may be far lower than those of an external testing machine capable of providing high-frequency signals. Further, different from the testing architecture shown in FIG. **1**, the concept of the present invention may be applied to various types of signal processing systems. For example, the concept of the present invention is not limited to the application of a transmitting circuit in a same signal processing system, and may be further applied to a signal processing system that does not include a transmitting circuit.

In an alternative embodiment, the connection between the translational filter **23** and the module under test **21** may be different from that shown in FIG. **5** to perform different tests. For example, the nodes IN_P and IN_N at the high-frequency side of the mixer **23**A may be respectively coupled to two output ends of the LNA **21**A. Alternatively, the nodes IN_P and IN_N at the high-frequency side of the mixer **23**A may be respectively coupled to two output ends of the amplifier **21**D.

In one embodiment, when the signal processing system **200** is in the testing mode, the connection between the baseband filtering circuit **23**B and the low-frequency side of the mixer **23**A is disconnected. In other words, in the testing mode, the capacitor elements C_I and C_Q may be selectively separated from the connection path between the mixer **23**A and the testing module **24**, so as to prevent from affecting the testing signal transmitted from the testing module **24** to the mixer **23**A.

In one embodiment, as shown in FIG. **6**(A), the signal processing system **200** further includes a correction module **24**. According to the testing result (e.g., an output signal from the ADC **21**E) that the module under test **21** generates in response to the set of high-frequency testing signals provided from the translational filter **23**, the correction module **25** determines a correction setting for the module under test **21**. Thus, non-ideal factors (e.g., mismatch between elements) in the module under test **21** may be counteracted, such that the output result from the module under test **21** more closely approaches an ideal value. Taking the architecture shown in FIG. **6**(A) for example, the above correction setting may be utilized to adjust a DC offset in the ADC **21**E.

In another embodiment, as shown in FIG. **6**(B), the correction setting generated by the correction module **25** is utilized to control the testing module **24**. As previously described, in the testing mode, the correction module **25** determines a correction setting for the module under test **21**. When the signal processing system **200** is later in the normal operation mode, the correction module **25** controls the testing module **24** to provide a set of non-converted correction signals to the low-frequency side of the mixer **23**A according to the correction setting, so as to generate a set of correction signals at the high-frequency side of the mixer **23**A. The set of correction signals and common externally inputted signals simultaneously enter the module under test **21**. For example, the set of non-converted correction signals may include a DC signal, such that the set of correction signals forwarded into the module under test **21** may compensate the non-ideal factors in the module under test **21**, e.g. eliminating the DC offset or carrier leakage. In practice, the correction signals that the translational filter **23** sends from the two nodes IN_P and IN_N may be different. According to actual requirements, the set correction signals may provide different correction amounts for the two differential paths. Details of the correction setting and designs of the correction signals are known to one skilled person in the art, and shall be omitted herein.

As shown in FIG. **7**, the concept of the present invention is also applicable to a single-ended input device under test. A module under test **71** in the signal processing system **700** is similar to the module under test **21**. A main difference of the module under test **71** from the module under test **21** is that, a signal to be processed by an LNA **71**A, a mixer **71**B, a filter **71**C, an amplifier **71**D and an ADC **71**E is a single-ended signal instead of differential signals. In the above situation, one of the two differential input ends IN_P and IN_N (the input end IN_N in this example) of the translational filter **23** is connected to an input end RFIN of the LNA **71**A, and the other input end (the input end IN_P in this example) of the translational filter **23** is connected to ground. Similarly, the signal provided by the testing module **24** may be up-converted by the translational filter **23** and then transmitted to the module under test **71** to be utilized for testing or correction.

According to another embodiment of the present invention, a testing method that generates a high-frequency testing signal by a translational filter is provided. FIG. **8** shows a flowchart of the testing method. The translational filter includes a mixer, which has a high-frequency side and a low-frequency side. In step S**82**, a testing signal is provided to the low-frequency side, so as to generate a high-frequency testing signal at the high-frequency side of the mixer. In step S**84**, in a testing mode, the high-frequency testing signal is provided to a signal input end of a module under test. In a normal operation mode relative to the testing mode, the translational filter provides the module under test with a filtering function.

Various operation details and modifications (e.g., performing correction after testing) in the description associated with the signal processing system **200** are applicable to the signal processing system **700** and the testing process **800**, and shall be omitted herein.

In conclusion, a signal processing system with a BIST function and a testing method thereof are disclosed by the present invention. With a translational filter that generates a testing signal in a chip, overall testing costs can be significantly lowered. Further, in additional to a transmitting circuit included in a same signal processing system, the testing method of the present invention is also applicable to a signal processing system that does not include a transmitting circuit.

While the invention has been described by way of example and in terms of the preferred embodiments, it is to be understood that the invention is not limited thereto. On the contrary, it is intended to cover various modifications and similar arrangements and procedures, and the scope of the appended claims therefore should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements and procedures.

What is claimed is:

1. A signal processing system, comprising:

a module under test, having a signal input end;

an oscillation signal generator, configured to generate an oscillation signal;

a translational filter, comprising a baseband filtering circuit and a mixer that is controlled by the oscillation signal, the mixer having a high-frequency side and a low-frequency side, the high-frequency side being coupled to the signal input end of the module under test, a low pass filter of the baseband filtering circuit being coupled to the low-frequency side; and

a testing module, configured to provide a testing signal to the low-frequency side, so as to generate a high-frequency testing signal at the high-frequency side of the mixer,

wherein the translation filter provides a bandpass filtering function controlled at least in part by the oscillation signal for the module under test in a normal operation mode and up-converts the test signal to generate a high-frequency testing signal at the high-frequency side of the mixer in a test mode.

2. The signal processing system according to claim **1**, wherein an oscillation frequency of the oscillation signal is adjustable.

3. The signal processing system according to claim **1**, wherein a frequency of the testing signal is adjustable.

4. The signal processing system according to claim **1**, wherein the testing module provides the testing signal when the signal processing system is in a testing mode.

5. The signal processing system according to claim **4**, wherein a connection between the baseband filtering circuit and the low-frequency side is disconnected when the signal processing system is in the testing mode.

6. The signal processing system according to claim **1**, wherein the testing signal is a DC signal.

7. The signal processing system according to claim **1**, wherein the testing module comprises a digital-to-analog converter (DAC) configured to output a low-frequency signal as the testing signal.

8. The signal processing system according to claim **1**, further comprising:
   - a correction module, configured to generate a correction setting according to a testing result that the module under test generates in response to the high-frequency testing signal.

9. The signal processing system according to claim **8**, wherein the testing module provides a non-converted correction signal according to the correction setting to the low-frequency side when the signal processing system is in a normal operation mode, so as to generate a correction signal at the high-frequency side of the mixer.

10. The signal processing system according to claim **9**, wherein the non-converted correction signal is a DC signal.

11. A testing method, that generates a high-frequency testing signal by a translational filter, the translational filter comprising a mixer having a high-frequency side and a low pass filter coupled to a low-frequency side, the testing method comprising:
   - providing an oscillation signal for controlling the mixer;
   - providing a testing signal to the low-frequency side, so as to generate a high-frequency testing signal at the high-frequency side of the mixer;
   - in a testing mode, up-converting by the translational filter the testing signal to the high-frequency testing signal to a signal input end of a module under test; and
   - in a normal operation mode, providing by the translational filter a bandpass filtering function controlled at least in part by the oscillation signal for the module under test.

12. The testing method according to claim **11**, wherein the mixer is controlled by an oscillation signal, the testing method further comprising:
   - adjusting an oscillation frequency of the oscillation signal.

13. The testing method according to claim **11**, further comprising:
   - adjusting an oscillation frequency of testing signal.

14. The testing method according to claim **11**, wherein the testing signal is a DC signal.

15. The testing method according to claim **11**, further comprising:
   - determining a correction setting for the module under test according to a test result that the module under test generates in response to the high-frequency testing signal.

16. The testing method according to claim **15**, further comprising:
   - when the module under test is under the normal operation mode, providing a non-converted correction signal to the low-frequency side according to the correction setting, so as to generate a correction signal at the high-frequency side of the mixer.

17. A testing signal generator, configured to provide a high-frequency testing signal to a signal input end of a module under test, comprising:
   - an oscillation signal generator, configured to generate an oscillation signal;
   - a translational filter, comprising a baseband filtering circuit and a mixer that is controlled by the oscillation signal, the mixer having a high-frequency side and a low-frequency side, the high-frequency side being coupled to the signal input end of the module under test, a low pass filter of the baseband filtering circuit being coupled to the low-frequency side; and
   - a testing module, configured to provide a testing signal to the low-frequency side, so as to generate a high-frequency testing signal at the high-frequency side of the mixer,
   - wherein the translation filter provides a bandpass filtering function controlled at least in part by the oscillation signal for the module under test in a normal operation mode and up-converts the test signal to generate a high-frequency testing signal at the high-frequency side of the mixer in a test mode.

18. The testing signal generator according to claim **17**, wherein the testing signal is a DC signal.

19. The testing signal generator according to claim **17**, wherein the testing module comprises a DAC configured to output a low-frequency signal as the testing signal.

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